GMI EFFECT IN $Co_{70,5}Fe_{4,5}Si_{15}B_{10}$ AMORPHOUS GLASS-COATED MICROWIRES

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Ferromagnetic amorphous glass-coated microwires are progressive materials that exhibit very useful behavior, like the giant magnetoimpedance (GMI) effect, which is the base the operating principles for different magnetic sensors. The field sensitivity of a typical GMI sensor can reach a value as high as 500%. In order to obtain large GMI values, it is necessary to choose the optimal chemical composition of the wire material with large permeability and small penetration depth. This work is aimed to study the magnetic properties of $Co_{70,5}Fe_{4,5}Si_{15}B_{10}$ alloys for GMI sensor application. Low prices and high flexibility of GMI sensors will warrant wide-ranging application in the near future.

K e y w o r d s: ferromagnetic amorphous alloy, glass-coated microwire, GMI effect

1 INTRODUCTION

When soft magnetic conductor is subjected to a small alternating current a large change in the complex impedance of the conductor can be achieved upon applying a magnetic field. This is known as the giant magnetoimpedance (GMI) effect [1-3].

2 THEORETICAL BASIS

Complex impedance $Z = R + j\omega L$ (*R* and *L* are resistance and inductance, respectively) of a magnetic conductor is given by the ratio U_{ac} / I_{ac}, where I_{ac} is the amplitude of a sinusoidal current passing through the conductor and U_{ac} is the voltage measured between the ends of the conductor. For a cylindrical ferromagnetic conductor it was defined as [4]:

$$Z = R_{dc} kr \frac{J_0(kr)}{J_1(kr)} \tag{1}$$

where J_0 and J_1 are the Bessel functions of the first kind, *r* is the radius of the wire, R_{dc} is the electrical resistance for a direct current and $k = \frac{(1+j)}{\delta_m}$ with imaginary unit j, δ_m is the penetration depth in a magnetic wire, with circumferential permeability μ_Φ:

$$\delta_m = \frac{c}{\sqrt{4\pi^2 f \sigma \mu_\Phi}} \tag{2}$$

where *c* is the speed of light, σ the electrical conductivity, and $f = \omega / 2\pi$ is the frequency of the alternating current, I_{ac}.

According to equations (1) and (2), the GMI effect can be understood as a consequence of the increase of the skin depth until it reaches the radius of the wire *r* through the decrease of the circumferential permeability, μ_Φ. In order to obtain large GMI values, it is necessary to reduce skin depth by choosing magnetic materials that have large μ_Φ and small δ_m. The ideal magnetic properties, such as large magnetic permeability, were observed in nearly zero magnetostrictive Co-base amorphous magnetic microwires. Amorphous metallic alloys can be produced by a variety of rapid solidification processing techniques. The amorphous wires and microwires have usually been made by so called Taylor-Ulitovsky method [5]. Final product is glass-coated microwire with metallic core diameter between 0,8-30 μm and with glass coating thicknes of 2-15 μm.

3 EXPERIMENT

Our amorphous microwires with nominal composition $Co_{70,5}Fe_{4,5}Si_{15}B_{10}$ were prepared in Instituto de Sciencia Materiales, Spain. The sample was 4 cm long, with the total diameter of 9 μm and diameter of metallic parts of 7 μm.

The field dependence of the impedance Z has been measured by four-point method at room temperature. Electrical voltage U_{ac} was estimated using oscilloscope. Values of the impedance *Z* has been calculated from U_{ac} and I_{ac}. The magnetoimpedance ratio $\Delta Z/Z$ was calculated from

$$\frac{\Delta Z}{Z}(\%) = \frac{Z(H) - Z(H_{max})}{Z(H_{max})}.100\%$$

where $Z(H)$ and $Z(H_{max})$ are the impedance of the microwire in the measured external magnetic field and maximum magnetic field to saturate the wire, respectively. The dependences of the relative impedance $\Delta Z/Z$ on the applied external magnetic field were investigated for different frequency of the sinusoidal current f = 1,8 MHz, 2 MHz and 2,2 MHz. Measurement was made during increasing and decreasing applied *dc* magnetic field, *H*.

4 RESULTS AND DISCUSSION

Figure 1 shows that GMI in glass-coated $Co_{70,5}Fe_{4,5}Si_{10}B_{15}$ microwire depend on measuring frequency and achieves 19%, 23% and 24% for frequencies 1,8 MHz, 2 MHz and 2,2 MHz. In this frequency region, the skin effect in GMI is dominant and at higher f the higher value $\left[\frac{\Delta Z}{Z}(\%)\right]_{\max}$ was found.

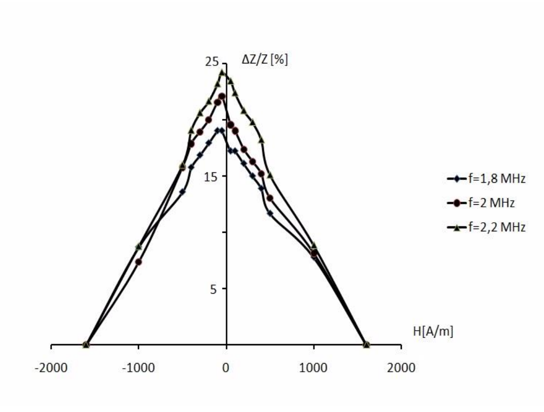

Fig.1: Influence of varying frequency on the GMI effect (*f* = 1,8 MHz, 2 MHz and 2,2 MHz).

In accordance with eq. (2), the magnetoimpedance increases with frequency because the impedance is proportional to $(f.\mu_{\Phi})^{-1/2}$.

As it is seen in Fig.1, in all three cases, there is a small asymmetry in the GMI curve with respect to increasing and decreasing external magnetic field *H*. The origin of this hysteretic behaviour can be related to the hysteresis of the magnetisation process and to the spatial distribution of magnetic anisotropy, which determines the domain structure in amorphous ferromagnetic microwires.

5 CONCLUSIONS

We found that $Co_{70,5}Fe_{4,5}Si_{10}B_{15}$ amorphous microwire exhibits the GMI effect. The magnitude of GMI and its sensitivity varies with measuring frequency and achieved values 19%, 23% and 24% for frequencies 1,8 MHz, 2 MHz and 2,2 MHz. The maximum value of GMI effect experimentally observed is much smaller than the theoretically predicted value. The special thermal treatment is necessary to further improve the GMI in $Co_{70,5}Fe_{4,5}Si_{10}B_{15}$ microwires.

Small hysteretic GMI behaviour was observed.

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